| Environmental Control and Life Support | Console Position: ETHOS |
|---|---|
| **States of Matter, Stoichiometry, Thermochemistry** | |

# Regenerative Environmental Control and Life Support System (Regen ECLSS)

## How Are the Gases Onboard the International Space Station Recycled?

### Instructional Objectives

Students will

- write a balanced equation for electrolysis reaction;
- predict the direction of oxidation-reduction reactions;
- determine the oxidation numbers before and after reaction;
- use $\Delta G°_{rxn}$ to determine behavior of reaction; and
- determine the mass and volume relationship.

### Degree of Difficulty

This problem requires students to integrate several aspects of the AP Chemistry curriculum to obtain the solution. For the average AP Chemistry student, the problem may be moderately difficult.

### Total Time Required

Teacher Prep Time: 5–10 minutes

Class Time: 60–80 minutes

*(To decrease amount of class time, students may complete research as homework via the Internet using the ISSLive! website or mobile application.)*

- Introduction: 5–10 minutes
- Student Research: 20–25 minutes
- Student Work Time: 25–30 minutes

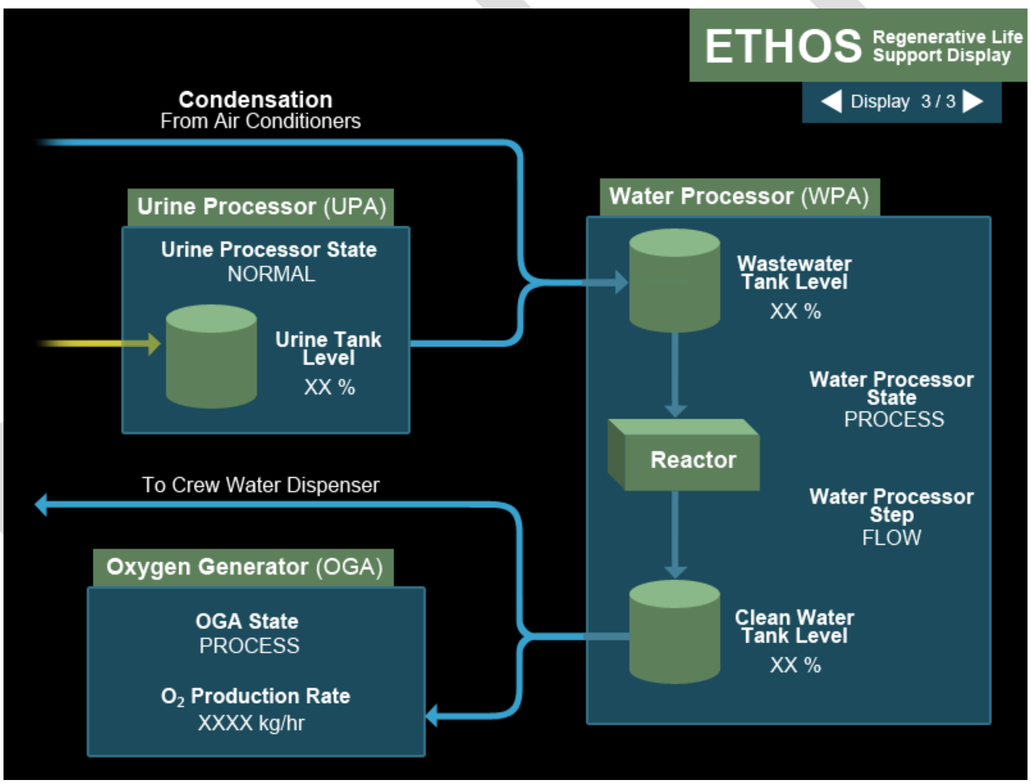
- Post Conclusion: 10–15 minutes

## Lesson Development

This problem is part of a series of problems associated with the NASA International Space Station *Live!* (ISS*Live!*) website at http://spacestationlive.jsc.nasa.gov.

### Teacher Preparation

- Review the Environmental Control and Life Support information on the ISS*Live!* website. This may be found at the *Operations* tab, under *Core Systems*.
- Review the Environmental and Thermal Operating Systems (ETHOS) Handbook, paying specific attention to the Regenerative Environmental Control and Life Support System (Regen ECLSS). This handbook may be found at the ETHOS console position in the 3D Mission Control Center environment (under the *Interact* tab, then *Explore Mission Control*).
- Review the ETHOS console display in the 3D Mission Control Center environment and the live data associated with the Regen ECLSS. The displays may be accessed by clicking on the console screens.




ETHOS Console Display

- Review the interactive activity at the ETHOS console position in the 3D Mission Control Center environment *by clicking on the rocket* on top of the console. This activity demonstrates the operations of the Regen ECLSS.
- Prepare copies of the STUDENT WORKSHEET (Appendix B).

### Inquiry-Based Lesson (Suggested Approach)

1. Pose this question to the class:

   *Since the International Space Station is a closed loop environment, how could the gases generated onboard be recycled for optimal use?*

2. Allow students to discuss the question in small groups or as a class. Have students build their own questions and possible solutions to the problem.
3. Distribute the STUDENT WORKSHEET to the class. Students may work individually or in small groups (2–3 members per group) to conduct the research. This may be assigned as homework.
4. In order to conduct the research, students should access the ISS*Live!* website and explore the 3D Mission Control Center. If needed, guide students to the ETHOS console position. They should access the ETHOS Handbook and ETHOS console displays, as well as the interactive activity, as they prepare to answer the questions on the STUDENT WORKSHEET.
5. Once the research is completed, students may work individually to complete the questions on the STUDENT WORKSHEET. They should refer to the live data on the ETHOS console displays located on the ISS*Live!* website to answer the entire problem.

### Post Conclusion

6. A SOLUTION KEY (Appendix A) is provided below using data that is typical for normal operations of the Regen ECLSS. Students' answers will vary depending on the actual live data.
7. Have students discuss their answers in small groups or with the entire class and tie back to the original question:

   *Since the International Space Station is a closed loop environment, how could the gases generated onboard be recycled for optimal use?*

8. Ask students to explain the Regen ECLSS and the data they used in their calculations.
9. Assessment of student work may be conducted by using the provided rubric (modeled after AP Free Response Question scoring).

### Extension

Other possible uses for the ISS*Live!* website, focusing on ETHOS and Regenerative Environmental Control and Life Support System:

- Calculate the Gibb's free energy associated with the reaction that occurs based on the provided enthalpy and entropy values.
- Based on Le Chatelier's principles, have students write the equilibrium expression and explain optimal conditions for increasing the yield of water.

## AP Course Topics

### Reactions

- Stoichiometry
    - Balancing of equations
    - Mass and volume relations with emphasis on the mole concept, including empirical formulas and limiting reactant
- Thermodynamics
    - First law: change in enthalpy; heat of reaction
    - Second law: entropy
    - Relationship of change in free energy to equilibrium

### States of Matter

- Gases
    - Laws of ideal gases
        - Equation of state for an ideal gas
        - Partial pressures

## NSES Science Standards

### Science as Inquiry

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

### Science in Personal and Social Perspectives

- Science and technology in local, national and global challenges

### Physical Science

- Chemical reactions
- Conservation of energy and increase in disorder

### Science and Technology

- Abilities of technological design
- Understanding about science and technology

### History and Nature of Science

- Science as a human endeavor
- Nature of scientific knowledge

## Contributors

This problem is part of a series of problems developed by the ISS*Live!* Team with the help of NASA subject matter experts.

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## Scoring Guide

Suggested 15 points total to be given.

| Question | | Distribution of points |
|---|---|---|
| **1** | *1 point* | 1 point for the correct moles of carbon dioxide |
| **2** | *1 point* | 1 point for the correct moles of hydrogen gas |
| **3 a.** | *1 point* | 1 point for the correct balanced equation |
| **3 b.** | *2 points* | 1 point for the correct calculation set up<br>1 point for identifying the correct limiting reagent |
| **3 c.** | *1 point* | 1 point for the correct mass of water |
| **4** | *1 point* | 1 point for the correct explanation |
| **5** | *1 point* | 1 point for the correct explanation |
| **6** | *2 points* | 1 point for the correct explanation relating to temperature<br>1 point for the correct explanation relating to pressure |
| **7** | *1 point* | 1 point for the correct calculation of days |
| **8** | *1 point* | 1 point for the correct explanation |
| **9 a.** | *1 point* | 1 point for the correct partial pressure |
| **9 b.** | *2 points* | 1 point for the correct set up<br>1 point for the correct mass of oxygen gas |

APPENDIX A

**SOLUTION KEY**

# REGENERATIVE ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEM (Regen ECLSS)

### How Are the Gases Onboard the International Space Station Recycled?

The Regenerative Environmental Control and Life Support System (Regen ECLSS) is primarily monitored and controlled by the Environmental and Thermal Operating Systems (ETHOS) flight controller. The ETHOS flight controller works in the Mission Control Center for the International Space Station (ISS), along with a team of other flight controllers. These flight controllers also monitor the operations of the ISS to keep the crewmembers and space station safe. To learn more, explore the 3D ISS Mission Control Center by accessing Explore Mission Control under the *Interact* tab on the ISS*Live!* website at http://spacestationlive.jsc.nasa.gov.

1. According to the EPA (Environmental Protection Agency), the average carbon dioxide output for any person per day is approximately 1.0 kilogram (kg). Visit the crew timeline under the OPS Planner console or by accessing from the *Live Data* tab to determine the number of crewmembers currently onboard. Then calculate the number of moles of carbon dioxide produced on the ISS per day by the crew that can be used for the production of water.

   Assume the OPS Planner display indicates 4 crewmembers onboard the ISS.

   $4 \cdot 1.0$ kg = 4.0 kg per day

   $$\frac{4.0\,\text{kg}\,CO_2}{\text{day}} \cdot \frac{1000\,\text{g}\,CO_2}{1\text{kg}\,CO_2} \cdot \frac{1\text{mol}\,CO_2}{44\,\text{g}\,CO_2} = 91\frac{\text{mol}\,CO_2}{\text{day}}$$

2. The Oxygen Generating Assembly (OGA) produces oxygen and hydrogen gas by passing an electrical current through water and breaking the molecules apart according to the following equation:

   $2\ H_2O\ (l) <=> O_2\ (g) + 2\ H_2\ (g)$

   This hydrogen is then fed into the Sabatier Reactor for the formation of water based on the above equation. Visit the ETHOS console display to find the amount of oxygen gas produced by the OGA, and determine the amount of hydrogen gas by-product created.

   Assume the ETHOS display indicates 1.2 kg per day of oxygen gas production per day.

   $$\frac{1.2\,\text{kg}\,O_2}{\text{day}} \cdot \frac{1000\,\text{g}\,O_2}{1\text{kg}\,O_2} \cdot \frac{1\text{mol}\,O_2}{32\,\text{g}\,O_2} \cdot \frac{2\,\text{mol}\,H_2}{1\text{mol}\,O_2} = \frac{75\,\text{mol}\,H_2}{\text{day}}$$

3. Based on the above information and calculations:

   a. Write a balanced equation for the reaction between carbon dioxide and hydrogen gas that occurs in the Sabatier Reactor.

      $CO_2\ (g) + 4\ H_2\ (g) <=> 2\ H_2O\ (l) + CH_4\ (g)$

   b. Determine the limiting reagent between the carbon dioxide and hydrogen gas.

      $$91\ \text{mol CO}_2 \cdot \frac{4\ \text{mol H}_2}{1\ \text{mol CO}_2} = 360\ \text{mol H}_2$$

      Only 75 moles of hydrogen gas are produced, so hydrogen gas is the limiting reagent.

   c. Calculate the amount of water in kilograms (kg) that can be produced per day at the current rate.

      $$75\ \text{mol H}_2 \cdot \frac{2\ \text{mol H}_2\text{O}}{4\ \text{mol H}_2} \cdot \frac{18\ \text{g H}_2\text{O}}{1\ \text{mol H}_2\text{O}} \cdot \frac{1\ \text{kg H}_2\text{O}}{1000\ \text{g H}_2\text{O}} = 0.68\ \text{kg H}_2\text{O}$$

4. The enthalpy, $\Delta H^\circ_{rxn}$, for the reaction is -965 kJ $mol^{-1}$. Is the total bond dissociation energy of the reactants or the total bond energy dissociation energy of the products larger? Justify your answer.

   The bond dissociation energy of the reactants must be higher. To determine bond dissociation energy, subtract the bond energy of the products from the reactants. If the value is negative, reactant energy is higher.

5. The value of the standard entropy change, $\Delta S^\circ_{rxn}$ for the reaction is -410 $J \cdot K^{-1}\ mol^{-1}$. Explain why this is a negative value.

   Negative entropy implies more order in the system. In the above reaction, two gases are forming a liquid and gas. Liquid is more organized.

6. Theoretically, the best yield of water should be achieved at low temperatures and high pressures. Explain.

   The reaction is exothermic, so lowering the temperature causes the reaction to shift towards the products since heat is a product.

   There are more moles on the reactant side of the reaction, so increasing the pressure will shift the reaction toward the side with less moles (which is the product side).

7. Suppose that aboard the ISS, the Water Recovery Assembly (WPA) malfunctions and the part needed to make the repair is not onboard. The water storage tank for the WPA is a 56.7 liter tank. (View the ETHOS console display and determine the amount of water within the storage tank.) If 0.93 liters of water per day per crew member is needed for the OGA, and 2.8 liters per day per crew member is needed for potable water, calculate how long the water in the storage tank will last the ISS crew.

Assume the ETHOS console display indicates the storage tank is 30% full.

The amount of water in the tank is:

0.30 · 56.7 liters of water = 17.01 liters of water

0.93 liters per day · 4 crewmembers = 3.72 liters per day for OGA

2.8 liters per day · 4 crewmembers = 11.20 liters per day for crew

Total needed = 14.92 liters per day

17.01 / 14.92 = 1.1 days

8. Any water produced on ISS would not be considered consumable until processed through the water recovery system and purified. If the system was out of commission, the crew would need a way to purify the water. On Earth, the water could simply be boiled to kill any harmful microbes, but this is not an option on the ISS. Explain why?

   There is no way to boil water on the ISS. Being in a microgravity environment makes this a difficult process.

9. ETHOS is also responsible for maintaining the atmosphere on the ISS. Visit the ETHOS console display and focus on the Tranquility Lab to calculate the following:

   a. Determine the partial pressure the trace gases are exerting within the Tranquility Lab. (For the total pressure, use the pressure reading from the Destiny Lab.)

      Total pressure = Sum of all gases partial pressures

      Assume following values from the ETHOS console display:

      $751.21 \text{ mmHg} = 147.01 \text{ mmHg } O_2 + 585.21 \text{ mmHg } N_2 + 6.00 \text{ mmHg } CO_2 + P_{trace}$

      $P_{trace} = 13.0 \text{ mmHg}$

   b. Given the volume of the Tranquility Lab is 75,000 liters (L), calculate the mass of oxygen gas that is within it.

      PV = nRT

$$R = 0.0821 \frac{\text{atm} \cdot \text{L}}{\text{mol} \cdot \text{K}}$$

$$P = 751.21 \text{mmHg} \cdot \frac{1 \text{atm}}{760 \text{ mmHg}} = 0.99 \text{ atm}$$

$$(0.99 \text{ atm})(75{,}000 \text{L}) = n\left(0.0821 \frac{\text{atm} \cdot \text{L}}{\text{mol} \cdot \text{K}}\right)(319 \text{ K})$$

$$n = 2800 \text{ mol } O_2$$

$$2800 \text{ mol } O_2 \cdot \frac{32 \text{ g} O_2}{1 \text{mol } O_2} \cdot \frac{1 \text{kg } O_2}{1000 \text{ g} O_2} = 90 \text{ kg } O_2$$

APPENDIX B

**STUDENT WORKSHEET**

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3. Based on the above information and calculations:

   a. Write a balanced equation for the reaction between carbon dioxide and hydrogen gas that occurs in the Sabatier Reactor.

   b. Determine the limiting reagent between the carbon dioxide and hydrogen gas.

   c. Calculate the amount of water in kilograms (kg) that can be produced per day at the current rate.

4. The enthalpy, $\Delta H^\circ_{rxn}$, for the reaction is -965 kJ $mol^{-1}$. Is the total bond dissociation energy of the reactants or the total bond energy dissociation energy of the products larger? Justify your answer.

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